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PATENT
03485-P0009A WWW

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicants	Robert Oliver Buckingham, *et al.*
Serial No. 10/736,354	Filing Date: December 15, 2003
Title of Application:	Link Assembly for a Snake Like Robot Arm
Confirmation No. 4073	Art Unit: 2837

Commissioner for Patents
Post Office Box 1450
Alexandria, VA 22313-1450

Submission of Priority Document

Dear Sir:

Applicants hereby submit a certified copy of the priority document, Great Britain Application No. 0114406,2, to perfect Applicants' claim of priority.

Respectfully submitted,

Wesley W. Whitmyer, Jr., Registration No. 33,558
Attorney for Applicants
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May 24, 2004

Susan K. Drammeh

The Patent Office
Concept House
Cardiff Road
Newport
South Wales
NP10 8QQ

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The Patent Office

Cardiff Road
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1. Your reference
DCE/LMS/34499

14JUN01 E637013-1 D00022
P01/7700 0.00-0114406.2

2. Patent application number
(The Patent Office will fill in this part)
0114406.2

13 JUN 2001

3. Full name, address and postcode of the or of each applicant *(underline all surnames)*

OLIVER CRISPIN CONSULTING LIMITED
5 Fallodon Way
Henleaze
Bristol BS9 4HR
United Kingdom

Patents ADP number *(if you know it)*

7321680001

If the applicant is a corporate body, give the country/state of its incorporation

4. Title of the invention

IMPROVEMENTS IN AND RELATING TO ROBOTIC ARMS

5. Name of your agent *(if you have one)*

"Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*

FJ CLEVELAND
40/43 Chancery Lane
London
WC2A 1JQ

Patents ADP number *(if you know it)*

07368855001

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Country	Priority application number *(if you know it)*	Date of filing *(day / month / year)*

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Number of earlier application	Date of filing *(day / month / year)*

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11. I/We request the grant of a patent on the basis of this application.

Signature F.J. Cleveland Date 13 June 2001

FJ CLEVELAND

12. Name and daytime telephone number of person to contact in the United Kingdom: Mr DC Evans - 020 7405 5875

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Improvements in and relating to robotic arms

This invention relates to an improvement in the robotic positioning of work tools and sensors and has particular reference to improved mechanical and software tools for positioning a work tool or sensor.

Traditionally, mechanical equipment such as engines and machines incorporating a housing have been subject to regular maintenance schedules. In the event of a malfunction, an operative or engineer will run the machine or engine through a series of test functions and take note of the reaction of the machine or engine. From an observation of the action or reaction of the machine to a given test function, it is possible to diagnose at least in part, the general area of malfunction of the machine. Thereafter the machine is dismantled to an extent sufficient to enable the possible malfunction to be identified and a repair effected.

Our co-pending British Patent Application No 0020461.0 describes and claims apparatus comprising a work head adapted to carry a tool or sensor to a site internally of a machine, which apparatus comprises a support arm for a work head, said arm being adapted to enter within said machine to position the work head in the desired operating position, operating means for operational control of said work head and control means for controlling the attitude and positioning of

the arm within said machine wherein the support arm comprises at least one segment having a plurality of links, each link being articulated with respect to its neighbour, and means for controlling the position and/or attitude of said segment relative to a datum thereby enabling the arm to follow and adapt to a predetermined path within the machine from entry to the machine housing to the work site. In a particular aspect of the invention described in that application, each segment comprises a plurality of links, there being a degree of articulation between adjacent links. By maintaining articulation of the links in each segment under tension, the spatial positioning of each segment can be controlled with precision to enable the arm to follow a convoluted path to guide the work tool into the machine.

The invention described in British Patent Application No 0020461.0 requires precise engineering of each component to minimise frictional losses at the point of articulation between each pair of links. In a multi-link segment, these friction losses build up and in a multiple segment robotic arm, the overall friction losses to be overcome during manipulation of the arm can become considerable. There is a need, therefore, for a device in which the manufacturer of the components is relatively straightforward and in which the friction losses can be reduced to the greatest extent possible. In the device specifically described in British Patent Application No 0020461.0, spring means may be provided to bias each of the

links one to another against the compressive tension force being exerted by the control cables.

The present applicants have found that by dispensing with the springs and interposing instead a layer of rubber or elastomeric material either bonded or keyed to the two members constituting the articulation between adjacent links within a segment, the rubber can constitute a fixed frictional contact surface between the articulated components while at the same time providing the resilient compression necessary to produce "stiffness" of the joint.

According to one aspect of the present invention, therefore, there is provided a link assembly for a robot arm which comprises:-

first and second link members each adapted for limited movement one with respect to the other and

elastomer means disposed between said first and second members and bonded or keyed thereto whereby movement between said first and second members results in shear movement within the elastomer means disposed between them.

The elastomer may be of a natural or synthetic rubber or any other suitable

resilient or elastomeric material. The elastomer is preferably disposed as a layer between said first and second link members. In one embodiment of the present invention, the first and second members may be configured in a co-operating mating relationship and the elastomer means may be disposed between them as a thin layer whereby a bending movement between the members produces shear movement within the elastomer means and reduces any compressive movement as a result of the relative movement between said first and said second members to a minimum.

It is preferred that the thickness of the layer is as thin as possible and the layers of 1 mm or less have been found to be advantageous. The layer may be bonded to one or both of the members or may be keyed to one or both. It is essential that each surface of the elastomeric layer contiguous a member should be effectively secured so that in operation relative movement between the members produces a shear movement within the elastomer. The thinness of the layer will reduce the tendency toward compression and will hence provide improved stability of the positioning of the component and will enhance the stiffness of each link component in the segment.

The elastomer means may comprise a plurality of layers of elastomer; a rigid layer bonded or keyed to adjacent elastomer layers may separate each layer. The

elastomer means may be a laminate. The interleaving or rigid layer between each layer of elastomer may be any rigid layer or material which is bondable to or capable of being keyed to the elastomer. The interleaving layer should be stiff enough to reduce compression of the elastomer to a minimum. Typical materials for the interleaving layer may be a thin metal layer, resin or glass fibre or may be a matt of either woven or unwoven material such as carbon fibre or kevlar.

The invention further includes a robotic arm containing at least one segment comprising a plurality of links in accordance with the invention, and control means for controlling the movement of said links within the segment wherein the control means maintains the said links under tension or compression. The control means may be at least one wire extending from one end of the segment of links to the other.

In a preferred aspect of the present invention, the control means may comprise three wires each extending from one end of the segment to the other, whereby changing the tension in the wires, one relative to the other, causes or allows the links to flex thereby controlling the movement of the segment. The wires are preferably tensioned to maintain the links under compression. The application of differential tension between the wires causes or allows the segment to move or bend.

In a particular embodiment of the invention each link may comprise of three components,

an outer disk which preferably has holes for the control wires so that the control wires extended externally of the other components of the link.

an inner disk which is adapted to be disposed generally inwardly of the outer disk and which has a central bore to accommodate control and/or power means for the work head, and

a rubber disk or layer extending between each inner and outer disk which is bonded or keyed to each but which is otherwise free-floating between said inner disk and outer disk so that the inner desk is not directly constrained by other components of the assembly .

A robotic arm may comprise a plurality of segments in accordance with the invention in which control means is provided for each segment. Each segment may terminate in an end cap having wire conduit means for the control wires of other segments of the arm and anchorage means arcuately spaced about the cap for securing the control wires for the segment in question.

At least one of the members of each link is provided with means for guiding the wires from one end of the segment to the other. The wires may be disposed externally of the segment links. Each wire may terminate in a ferrule, which is adapted to engage with a corresponding recess in the end cap of a segment so that on tensioning the wires, the ferrule is brought into engagement with the end cap to exert a compressive load on each of the links to maintain the stiffness of the links in the segment.

Each control wire is operated by an actuator: where there are control wires for a plurality of segments, said actuators are spaced in one or more arcs about a head board contiguous one end of the first segment. Typically the actuator array may provide one actuator for each wire andy they may be disposed in a spaced arcuate relationship to define a frustocone. The wire from each actuator may be passed about a guide such as a pulley to provide a fair lead for the control wire.

It will be apparent from the person skilled in the art that a segment can be built as a series of links or the complete segment may be assembled in a template with the elastomer being injected into the interstices between the components as in the form of a mould tool. In this way, it is possible to produce bonded complete segments relatively easily and quickly.

In an alternative embodiment of the present invention, each link may be produced as pairs of half-links which may then be assembled back to back. In this way, an inner link and an outer link half may be assembled with its bonding rubber layer. The link halves may then be assembled back to back or front to front to form the unitary link components, a plurality of which together form a segment.

The present applicants have found that it is possible to produce each half link component in three separate individual components, namely an outer link element, an inner link element and the rubber bearing. All that is required is that the bearing should be keyed or bonded to each of the link elements so that on attempting to move one component relative to the other, shear movement or force is generated within the rubber component. The assembled half-links can then be "pinned" together by means of locating dowels provided in mating holes on each of the assembled half-links. The assembly can be produced "loose" and the cables can be threaded through the various operating holes in the outer link periphery coupled to the actuator board. Once the actuators act to produce a degree of tension in the board, the whole assembly is held together so that by varying the tension in the wires, the segment can be manipulated as appropriate. The first and second elements constituting the components of each part link, may define for its intermediate rubber component, either a spherical or conical cavity or something in-between a sphere or cone or perhaps even toroidal. If the component is

spherical, then as the inner disc is rotated in relation to the outer disc, all the deformation of the spherical component is carried out through shear. If the component design is changed so that it is no longer spherical, any rotation of one part in relation to the other causes the bulk modulus of the elastomer to be exercised, that is to say as well as shearing the component, we are also causing local tension and compression parallel to the link axis. This makes any non-spherical joints stiffer than a spherical joint with equivalent basic dimension.

As has been indicated above, there is a significant advantage in replacing the rubber or metal rubber part of each link with multiple layering in order using two more, thin pieces of metal. This enables such a link to have a greater range of motion more effectively than simply doubling the number of links per segment. The length added to a link to increase the angle by a factor of 2 is less than double the original link. The thin rigid shell between the two rubber components serves to constraint the rubber parts such that the two rubber parts provide about the same shear stiffness as a single rubber part of double the thickness, but the two rubber parts of lesser thickness are stiffer in compression than a single part of double the thickness.

In this particular embodiment, if two adjacent links are flexed so that the outer peripheries are brought together, the diametrically opposite "bottoms" tend to

move apart and thus serve to define a segment of an annulus. In this circumstance, the inner discs are free to move in relation to the outer discs. The object of the design is to maintain the centre of rotation stationary and at a position at the centre of each inner disc in the undeformed position. In essence this works like a ball and socket joint with no friction other than hysteresis losses within the rubber and a small amount of actual compressibility in order to maintain stiffness of the joint.

By using elastomeric discs or bearings between each of the moving parts of each link, there is a significant reduction in friction and at the same time, the device becomes extremely easy to manufacture in bulk. Once tools and templates have been produced, therefore, the reproduction of large numbers becomes relatively easy. Segments made up of a significant number of links can be produced and the optimum control for each segment is 3 wires. While it is possible to dispense with perhaps one of the wires in a segment or at least one of the operating wires in a segment, maximum manipulation can best be obtained using a three wire arrangement.

For a multi-segment arm, three sets of control wires will be required for each segment, thus an eight segment arm will require 24 control wires in all, with a separate actuator control for each wire.

By using apparatus in accordance with the present invention, it is possible to create paths by using a joy-stick control assembly for tip guidance, or in the alternative, off-line or on-line techniques can be provided for computer control through a CAD model of the proposed environment.

Following is a description with reference to the accompanying drawings of embodiments of the device in accordance with the present invention.

In the drawings:-

Figure 1 is a perspective view of a plurality of links in a segment in accordance with the present invention.

Figure 2 is an exploded diagrammatic view of a "half" link of Figure 1.

Figure 3 is an end view of a link element or a half link element of Figures 1 and 2; and

Figure 3A is a cross-section on the line A-A of Figure 3.

Figure 4 is a perspective view of an end cap showing the ferrule attachment assembly at a remote end of a segment.

Figure 5 is a cross-section on the line A-A of Figure 6.

Figure 6 is an end view of an alternative embodiment of the present invention.

Figure 7 is an exploded diagram of an "half" link of the embodiment of Figures 5 and 6.

Figure 8 is a head board showing a three actuator arrangement for a single segment.

Figure 9 is a frustoconical array for a plurality of actuators for controlling a robotic arm having a plurality of segments.

The segments indicated generally at 10 comprises a plurality of link components indicated generally at 11. Each link component comprises an inner disc 12 and an outer disc and wire guide 13. The inner disc 12 is shaped to provide an arcuate convex surface indicated generally at 14 and the outer disc 13 has a matching arcuate concave surface 15. Assembled as shown in Figure 1, the inner disc 12 and the outer disc 13 are separated by a layer of rubber 16 which may be formed in situ or may be in the form of a separate stress relieving filet. The rubber layer 16 may be bonded to each of the outer disc 13 and the inner disc 12

to allow relative movement therebetween. Each inner disc is provided with a central bore indicated generally at 17 to define a central lumen through the centre of the device to accommodate a power supply and control mechanism for a work head at an extremity of the robotic arm. In construction, each link 11 is formed from a pair of "link halves" which are best indicated in Figure 2. Each link half comprises an outer link member 13, an inner link member 12 and a rubber disc or shell 16 adapted to be inserted between the two. The components may be bonded together to form a half link portion which may then be joined together with adjacent components to form the continuous segment 10 of links 11. It will be noted that the concave surface 21 of outer link element 13 is adapted to cooperate with the corresponding under surface (as shown in Figure 2) of element 12. The disc 16 is shaped to be accommodated between the two and the components are bonded together. This can be best seen from Figure 3A which shows a section through the bonded component. In one aspect of the invention, the outer disc and wire guide 13 is provided with a plurality of circumferentially spaced dowel holes 23 while the inner disc 12 is also provided with correspondingly spaced diametric dowel holes 24. When then assemblies are placed together with dowel pins located in holes 23 and 24 respectively, it will be appreciated by the person skilled in the art that if the assembly is then maintained under tension by the control wires therefore, permanent fixing will not be necessary. The outer disc 13 has a plurality of through bores 25 adapted to

constitute wire guide holes to accommodate the control wires for the device.

Each segment may be provided with an end cap 30 (see Figure 4) which is provided with peripheral spaced wire accommodating holes and with an enlarged recess 26 including a ferrule 27 affixed to the end of a control wire 28. In assembling the device, therefore, the end cap 30 is secured to the adjacent outer disc portion 13 of the end link and the control wires 28 are threaded through the appropriate recess 26 in the end cap 30 and then through mating holes 25 in each of outer disc portions 13 for each link in the segment.

The ends of the wires are passed back to actuators and are tensioned until the ferrule 27 is brought against the back plate of end 30 to maintain the assembly under tension. By tensioning the assembly in this way, it is possible to avoid the bonding of the components. As shown in Figures 5, 6 and 7, the mating faces of the inner and outer discs may be appropriately grooved to accommodate a correspondingly profiled rubber disc 16. These grooves or profiling serves to key the disc 16 in position between the inner and outer discs 12 and 13 respectively and yet allows for movement of one with respect to the other and response to changes in tension in the control wires 28. This avoids the need for bonding of the discs in place and allows for relatively easy replacement of damaged components within any given snake arm assembly.

In the assembled arm, the outer surfaces of the discs and the control wires may be sealed and the resultant cavity and wire guides fill with a lubricant so that the control wires to run in a lubricated environment. This again, serves to reduce loss and friction in service.

The movement of each segment may be controlled by adjusting the tension on each of the wires. Figure 8 shows a simplified three actuator control board which comprises a base member 40 having towards one end thereof an upstanding mounting plate assembly 41 adapted to mount an end plate of a segment 42. Control wires 28 extend through the mounting plate assembly 41 to the operating tubes 43 of each of actuators 44. The centre actuator 44 provides a direct feed for wire 28 from the segment to the actuator *per se* while those on either side of the centre operate via means of pulleys 45 to minimise any friction or wear in operation.

Each of actuators 44 may be controlled either manually or by computer to vary the tension in the three wires 28. Depending on the variants in the tension the individual links will seek to move in response to the changing tension in the wires thereby producing movement in the segments to permit guidance of the segment end to a given location in the environment or work place.

For multiple segments, of course, many more actuators will be required, usually three per segment. In these circumstances, it is necessary to locate the actuators to provide access to the control wires and exit from the control end of the first segment in a very small space. Accordingly, the actuators may be arranged in an arc so that the feed tubes for each actuator containing a control wire define a cone rather as shown in Figure 9.

The rubber discs 16 may be a single piece of rubber or may be in the form of a composite of alternate layers of elastomer and rigid interleave layer. The present applicants have found that the thinner the individual layers of rubber, the more efficient is the eventual layer and the stiffer the joint between the inner disc and the corresponding outer disc.

The apparatus in accordance with the present invention also provides a sealing of the bearing surfaces between the inner and outer discs and prevents the ingress of injurious matter from the atmosphere. Furthermore, the central bore or lumen 17 is effectively sealed and provides ready access for power supply and control means for a work head at the end of the robotic arm.

Not shown in the drawings is a sheathing provided externally of the outer surface of each of the outer discs and wire guides 13, which outer surfaces of the links

are effectively sealed, thereby permitting the interstices between each of the outer discs and wire guides and the sheath to be filled with oil or lubricant to permit the control wires to operate in a lubricating environment.

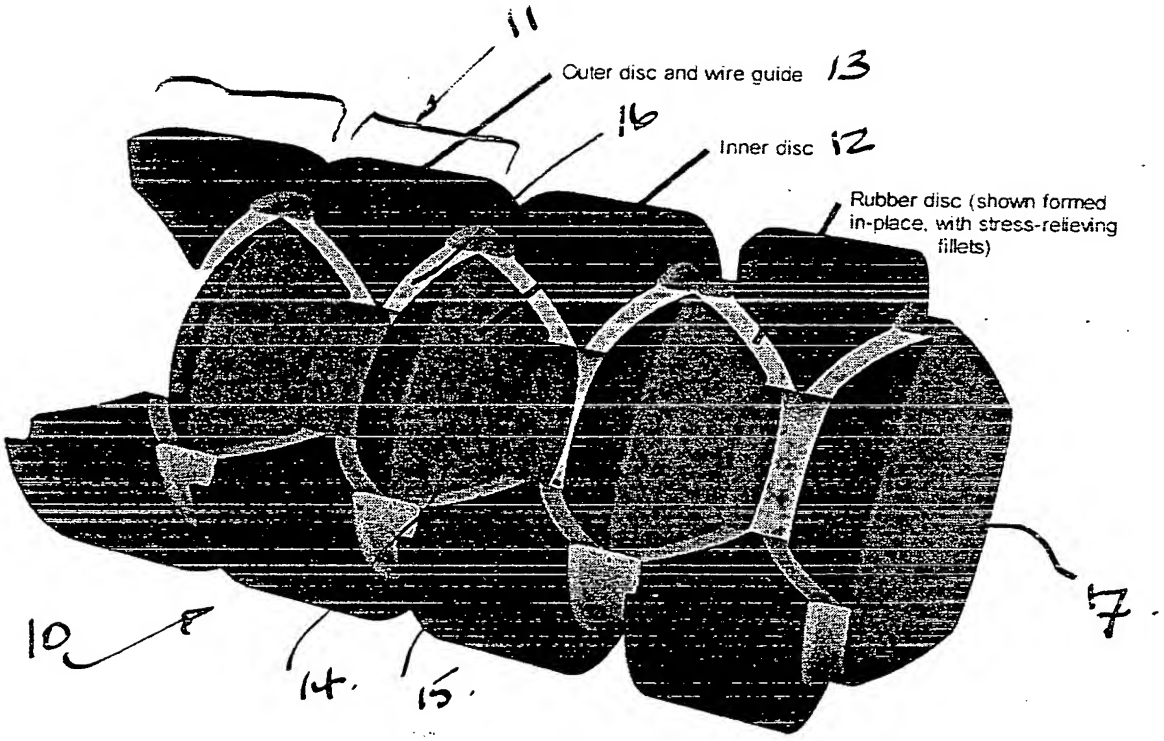

FIGURE 1

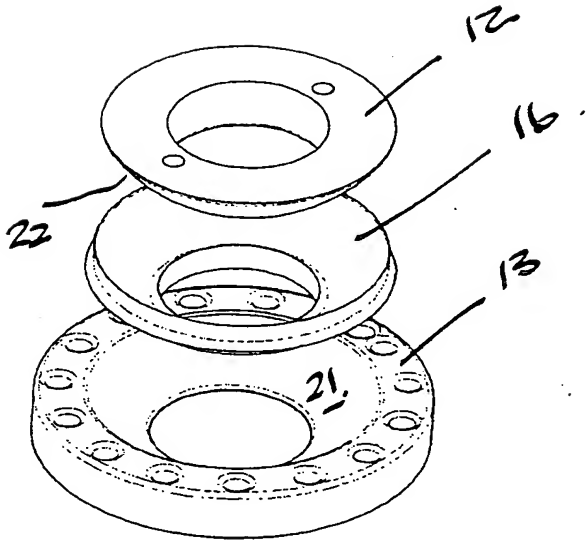

FIGURE 2

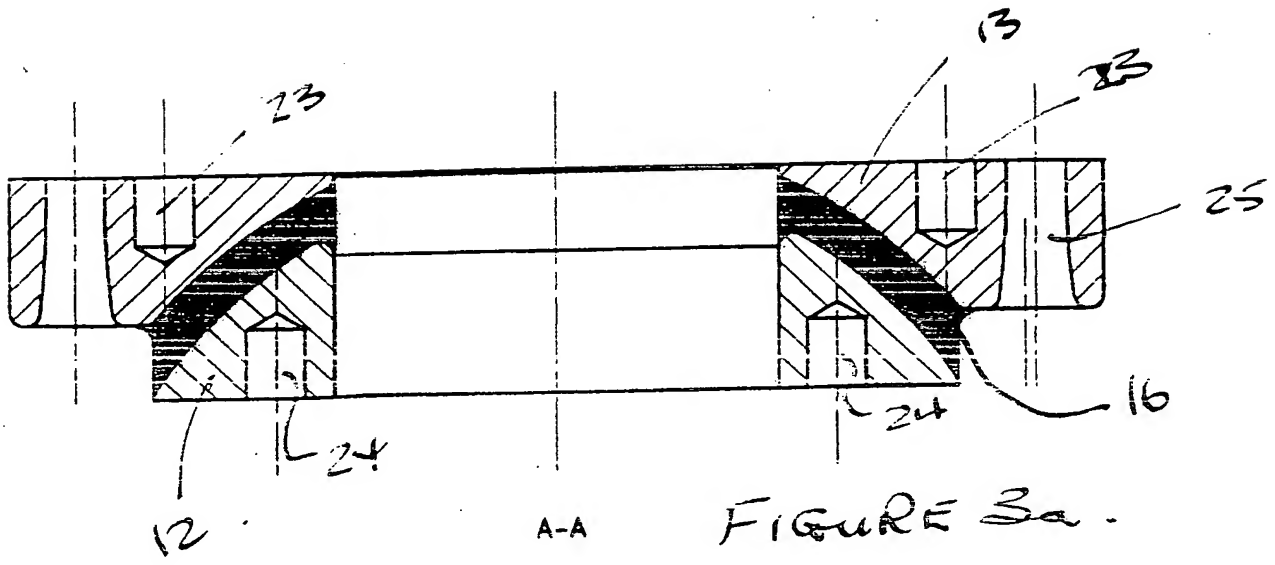

FIGURE 3a.

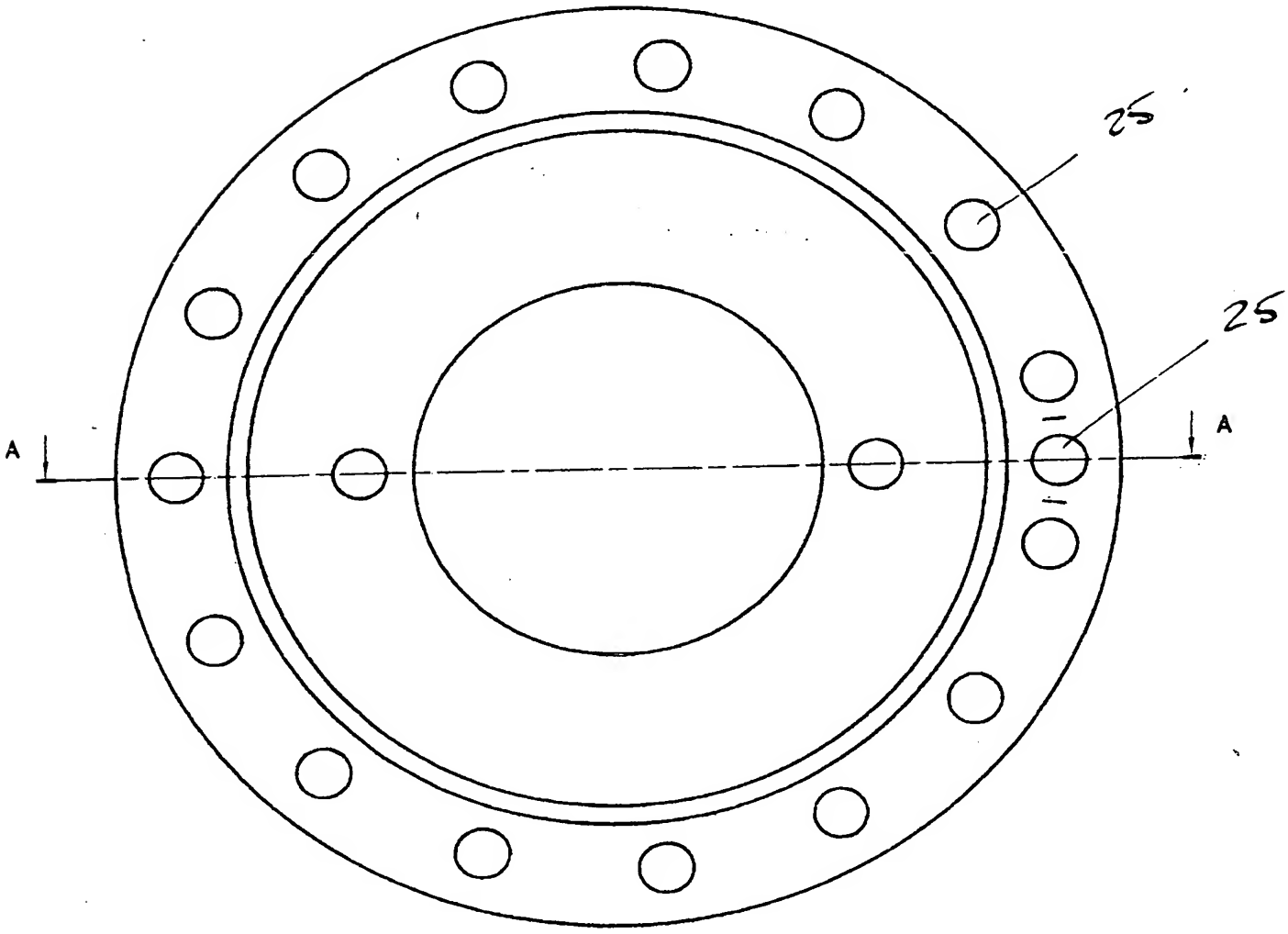

FIGURE 3.

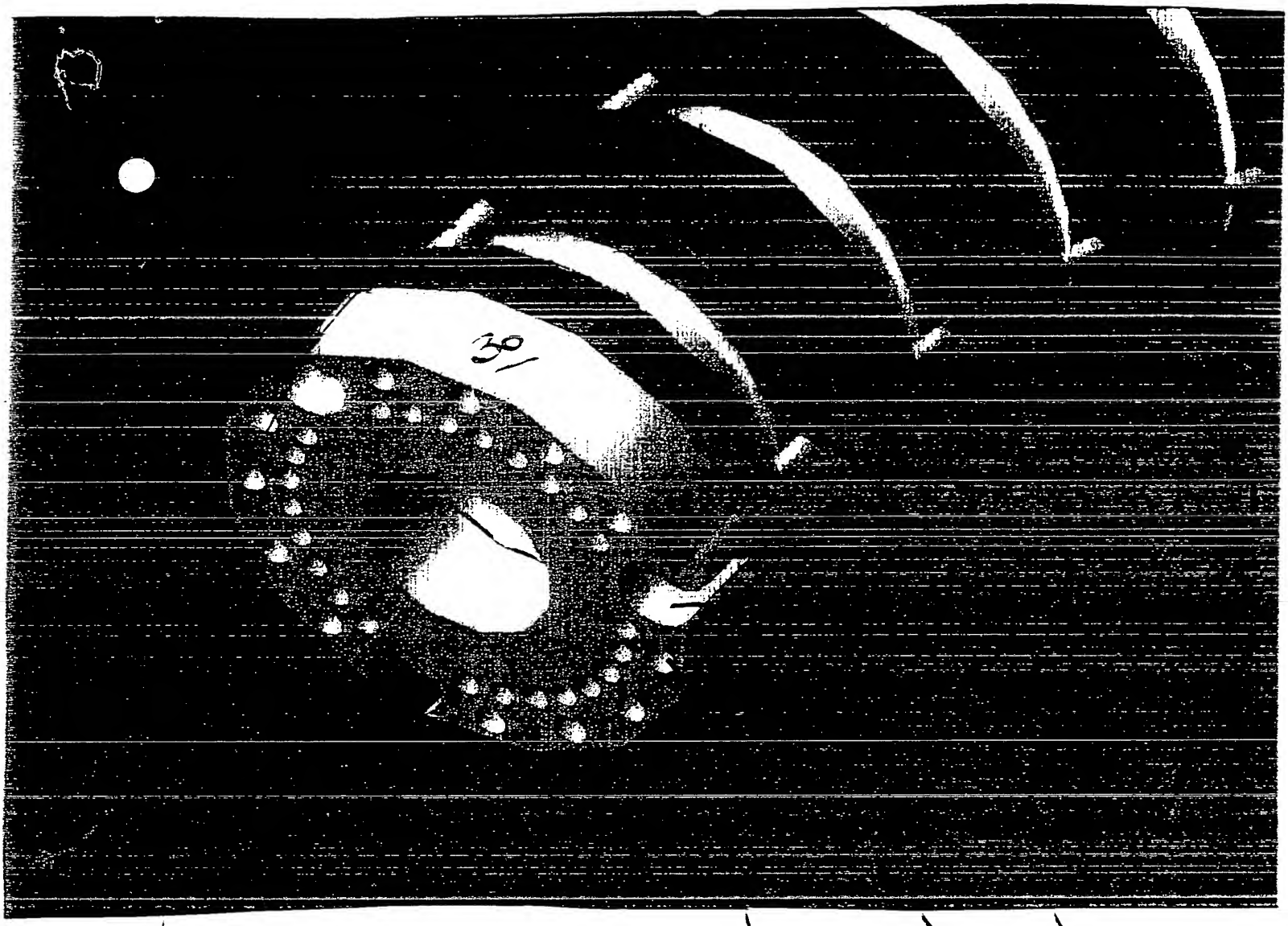

FIGURE 4.

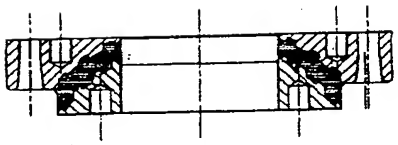

FIGURE 5.

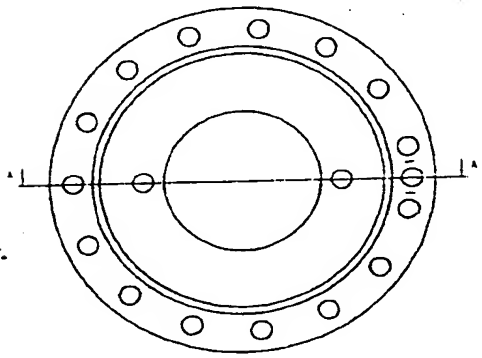

FIGURE 6.

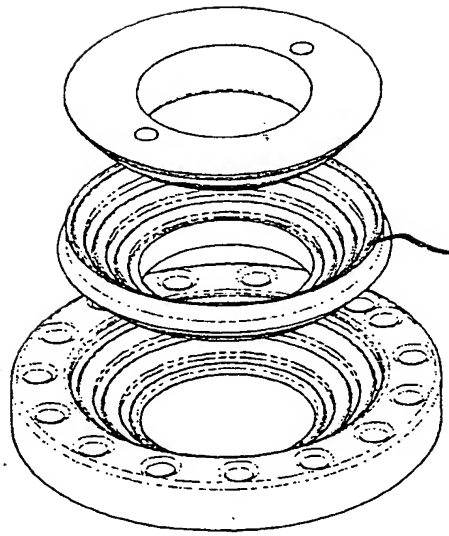

FIGURE 7.

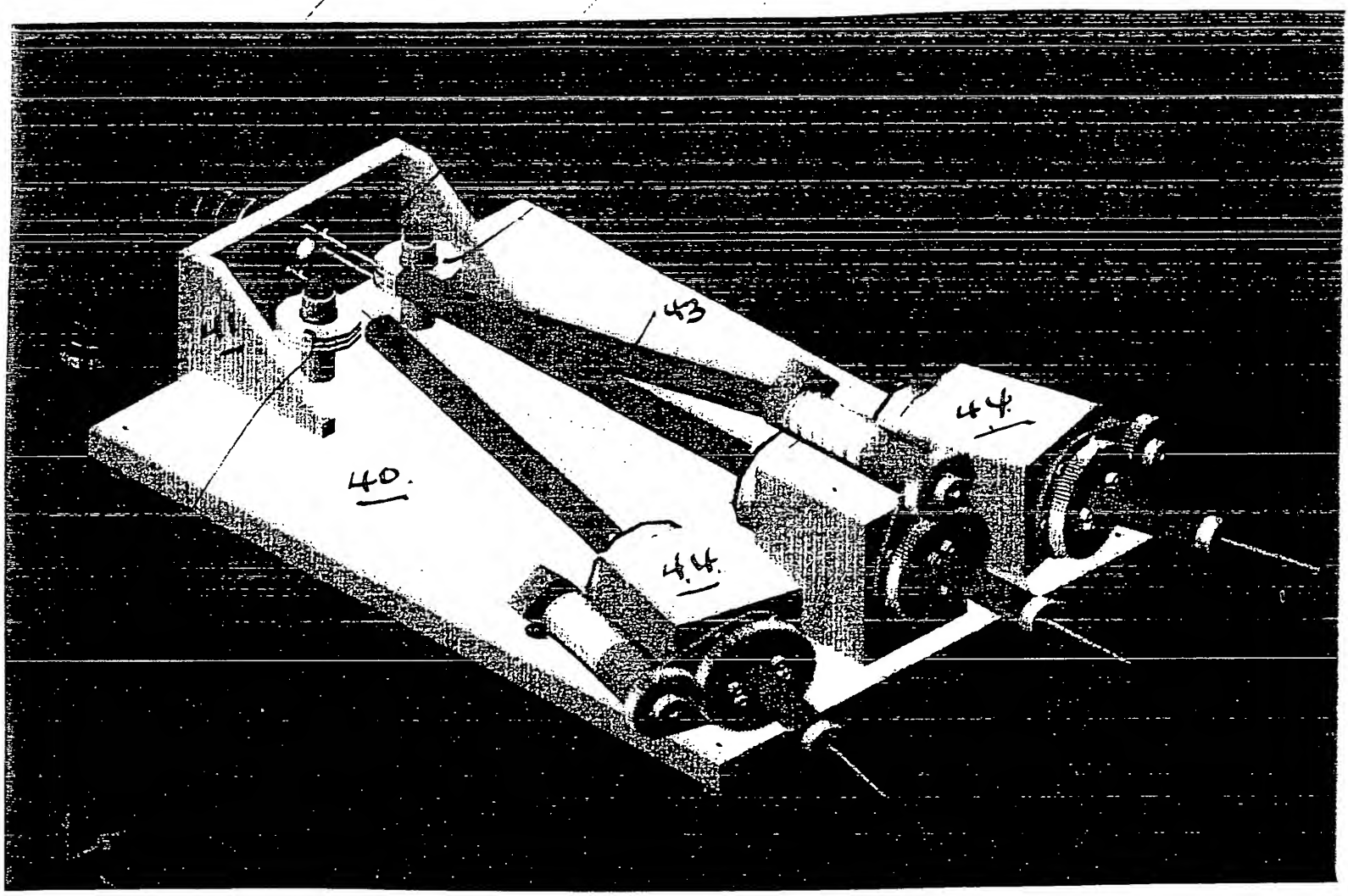

FIGURE 8.

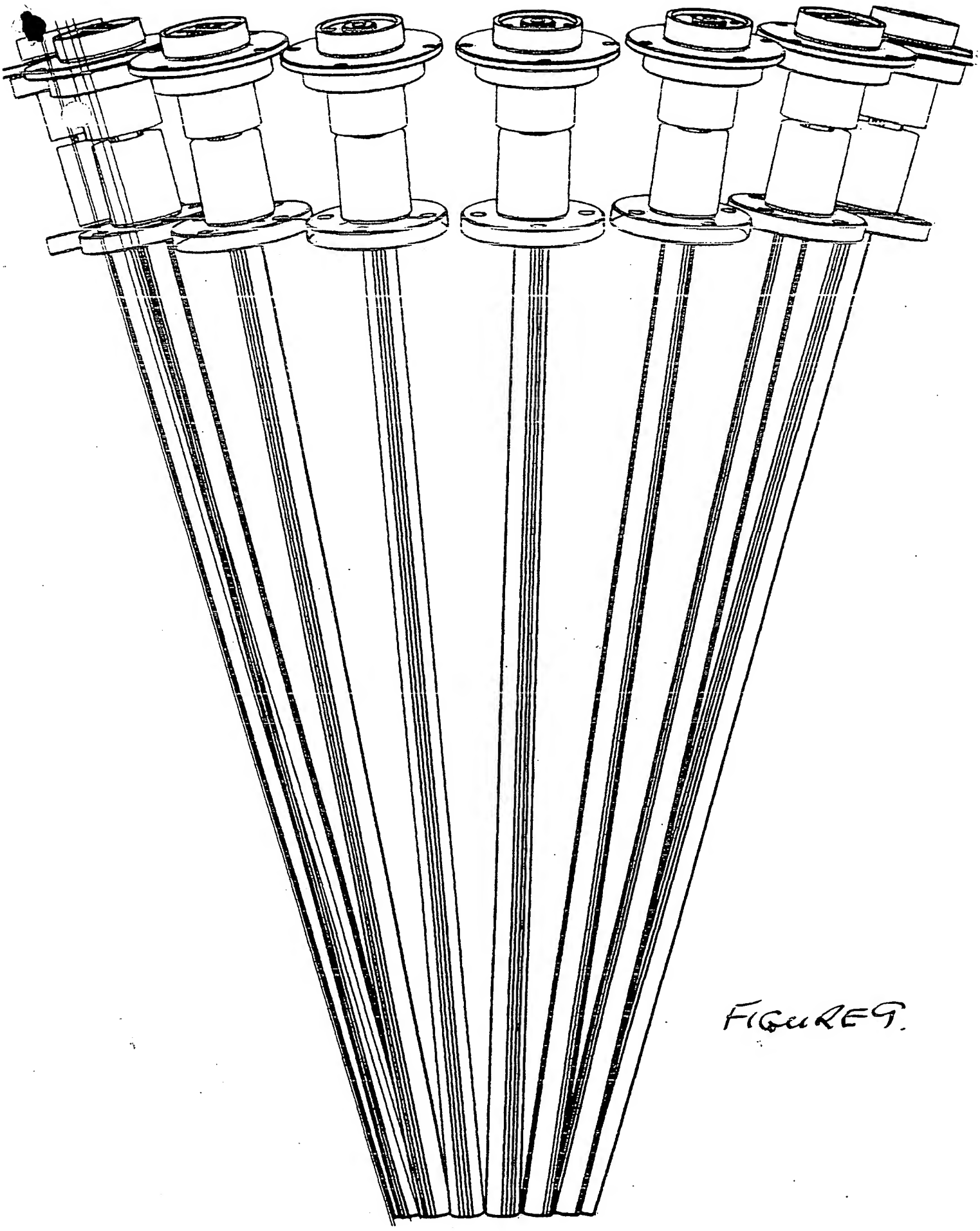

FIGURE 9.